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Development of a 10 N liquid bipropellant thruster for Geostationary spacecraft programme of Indian Space Research Organisation

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Low thrust level engines which can deliver small impulse bit are very much essential to provide better controllability of spacecrafts. A 10 N liquid bipropellant thruster with Nitrogen tetroxide and Monomethyl hydrazine has been developed by Liquid Propulsion Systems Centre of Indian Space Research Organisation to improve the attitude and orbit control capabilities of its geostationary spacecrafts. The thruster comprises of a coaxial swirl type injector, radiation cooled nozzle and series redundant valve with latchable upstream valve. Thrusters were qualified to meet the extreme conditions like injection pressure variation, propellant temperature variation, mixture ratio variation etc. At normal supply pressures it delivers a specific impulse more than 290 s. More than 100 flight thrusters were realized and delivered for eleven geostationary spacecrafts.

Introduction

Liquid Propulsion Systems Centre (LPSC) of Indian Space Research Organisation (ISRO) is responsible for the development of liquid bi-propellant thrusters for ISRO's launch vehicle and spacecraft programme. It has successfully developed and qualified Liquid Apogee Motor (LAM) and Attitude and Orbit Control System (AOCS) thrusters for its geostationary satellite (GEOSAT) programme. During earlier days 22 N thrusters were engaged for the attitude control and station keeping activities of geostationary spacecrafts. Later the development of a 10 N thruster was initiated to achieve better controllability of spacecrafts due to low value of minimum impulse bit delivered. It also gives better performance due to the higher area ratio which can be accommodated in the same envelope of 22 N thruster.

The 10N thruster was developed, qualified and 8 numbers were first used in GSAT-1 spacecraft in the year 2001. Since then similar thrusters were used in several geostationary spacecrafts of ISRO.

Design description

The 10 N thruster developed is a pressure fed liquid bi propellant thruster with Nitrogen tetroxide (MON-3) / Mono Methyl Hydrazine (MMH) propellant combination. This thruster

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comprises of a pair of thruster control valves, a swirl type injector and a thrust chamber. By design the combustion chamber and nozzle are cooled by radiation. An unintentional film cooling is available due to the inherent characteristic of the injector. This keeps the temperature of the combustion chamber close to the injector face to a low value. The thrust chamber parameters like characteristic length, contraction area ratio etc. were finalized based on experience gained from the development of similar 22 N thruster.

The combustion chamber and expansion nozzle are manufactured from columbium alloy which is silicide coated internally and externally to prevent oxidation at higher temperature. The nozzle is having an expansion area ratio of 200:1.

10N thruster assembly

The injector is of co axial swirl type with various components to impart swirl action for oxidiser and fuel. A thermal stand off is provided on injector to reduce heating of propellant in the injector flow passage by conduction from chamber. Trim orifices provisions are also available for both oxidizer and fuel passage. This enables each individual thruster to be tuned for specific inlet pressures.

The injector manifold volume downstream of thruster control valve was reduced to minimum possible to ensure faster response and better impulse bit repeatability at lower electrical pulse widths. Stiffeners are provided on injector flange to increase the natural frequency of the thruster above 1000 Hz.

The thruster flow control valve is a series redundant valve with latchable upstream valve. These valves are fully qualified for ISRO’s GEOSAT programme and flight proven.

The valves are assembled to injector using high strength, light alloy fasteners. Three seals are provided in valve injector interface to ensure leak tightness. The thrust chamber is electron beam welded to the injector. The thruster specification is given in table-1.

Thrust (Vacuum), N	10
Propellant combination	MON-3-MMH
Mixture ratio by weight (O/F)	1.65
Specific impulse, seconds (minimum)	285
Minimum impulse bit for 10 ms EPW, mNs	30
Weight (max), gms	990

Table-1 Thruster specification

Development and Qualification.

10 N thruster development programme was started in the year 1997 for ISRO's geostationary spacecraft GSAT-1. These thrusters were proposed in the east and west locations of attitude and orbit control system (AOCS). The development was carried out in two phases.

1. Sea level development
2. High altitude development.

Sea level development tests were carried out for a cumulative duration of 19,000s[1]. Flanged version thrust chambers which can be bolted to injectors were used for sea level developments.

The performance of various combination of injector elements were evaluated in the initial development. During the development the major problem encountered was the variation of mixture ratio with time in continuous mode firing. This problem was solved by suitably modifying the injector elements. The development started with a single seat valve and later the valve design was modified to a series redundant valve with latchable upstream valve.

A total of 7 thrusters were qualified as per the approved qualification test matrix of ISRO's GEOSAT programme. The major objectives of qualification were to demonstrate the performance characteristics over a wide range of operating conditions, the capacity of thruster to withstand stresses due to vibration, shock etc. Thrusters were subjected to sine and random vibrations. Overall random vibration level experienced was 20.9 g_{rms}.

The qualification firing in simulated high altitude condition includes tests at extreme conditions like

1. Continuous and pulse mode firing at different duty cycles in three different supply pressures corresponding to Beginning of Life (@ 1.65 MPa), Middle of Life (@ 1.4 MPa) and End of Life (@ 1.15 MPa).

2. Injection pressure variation tests from 0.9 MPa to 1.9 MPa
3. Mixture ratio variation test from 1.35 to 2.0
4. Propellant supply temperature variation test from -5 °C to 60°C.
5. Valve terminal voltage variation from 42 VDC to 28 VDC.

The major tests in the approved qualification matrix are steady state firing for 1000s, hot restart test ie, the thruster is restarted when the injector flange soak back temperature reaches maximum after a steady state firing, a train of 20,000 pulses each in three critical duty cycles etc. Qualification firings were carried out with flight version heat shield.

The qualification operating box of the thruster is shown in fig 1.

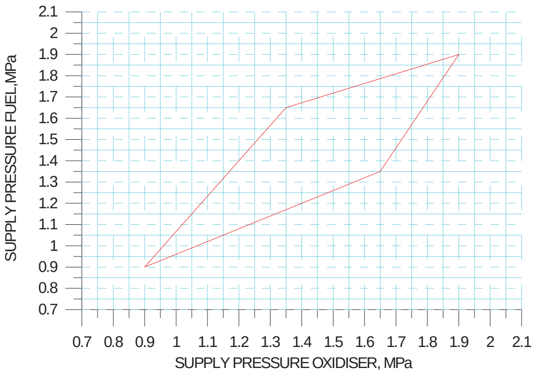

Fig-1 Qualification operating box

Valve heating cycle tests were conducted in one of the qualification hardware wherein both the valves were heated to 70°C for 9 days under nominal pressurised conditions and the thruster was fired on every third day to evaluate the performance. Afterwards the valves were heated to 95°C and soaked for half an hour and thruster firing was carried out to evaluate the performance. It has successfully undergone all the qualification tests recommended for ISRO's GEOSAT programme.

Details of qualification duration are given in table-2.

Sl. No	Thruster Idn.No	Cumulative duration, s	No of Pulses (million)
1	Q1	22500	0.245
2	Q2	26700	0.252
3	Q3	22500	0.271
4	Q4	17500	Nil
5	Q5	16650	Nil
6	Q6	38000	Nil
7	Q7	700 (Valve heating)	

Table-2

Performance Characteristics

The 10 N thruster operates at a nominal supply pressure of 1.65 MPa.

The variation in thrust with supply pressure is shown in fig-2.

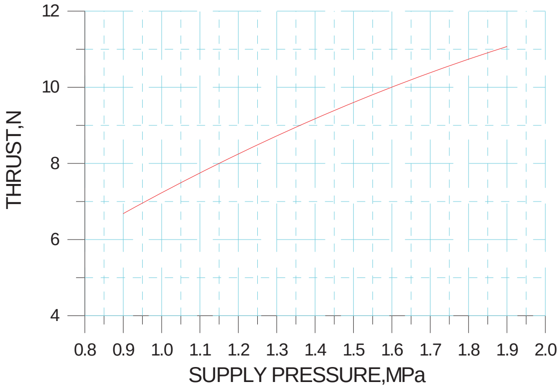

Fig-2

At nominal operating conditions this thruster delivers a specific impulse greater than 290s. The steady state specific impulse (ISP) achieved in qualification hardware at different supply pressures and at different mixture ratios are shown in fig-3 & fig-4.

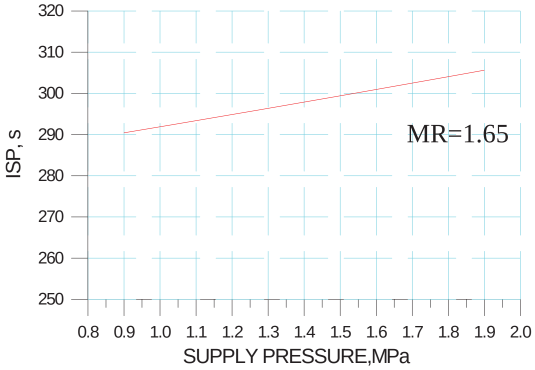

Fig-3

As feed pressure increases, the specific impulse also increases. This increase is due to better atomization of propellants at higher supply pressures.

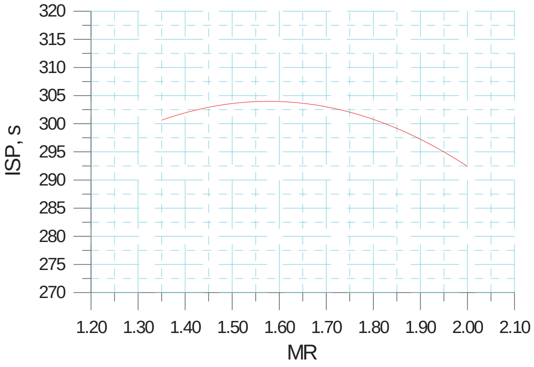

Fig-4

Tests were carried out over a mixture ratio range of 1.35 to 2.0. Maximum performance of thruster is observed between mixture ratios 1.50 and 1.70. The specific impulse remains more or less flat in this region.

The demonstrated specific impulse at rated supply pressure for last 25 hardware realized are shown in fig-5

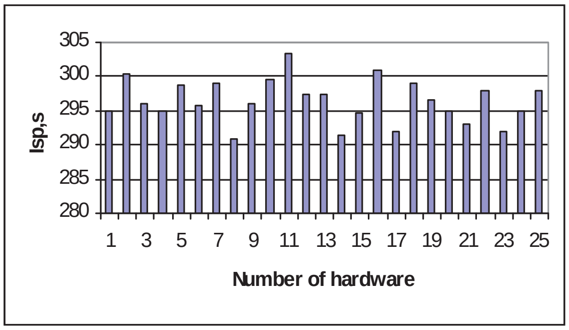

Fig-5 Demonstrated ISP of last 25 thrusters

A spread of nearly 10s in ISP is observed in hardware to hardware. It is due to the fact that the flow pattern of injectors with very small flow passages is sensitive to surface finish and dimensional tolerances.

Temperatures are measured in twelve locations on the hardware. The chamber and valve body temperature measurement location during the hot firing is shown in fig-6.

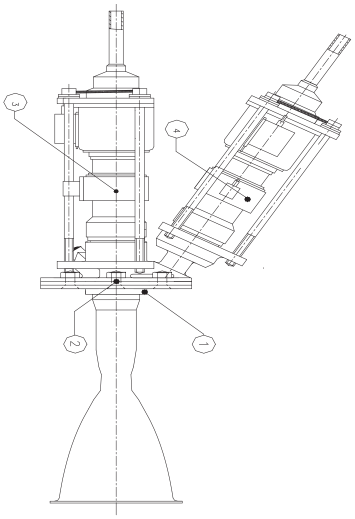

Fig-6

In 1000s continuous mode firing, the chamber and valve body temperatures are 180°C and 65°C respectively. Maximum soak back temperature experienced by valve body is 75°C which is well within the acceptable limits. Fig-7 shows the chamber and valve body temperatures for 1000 s steady state firing.

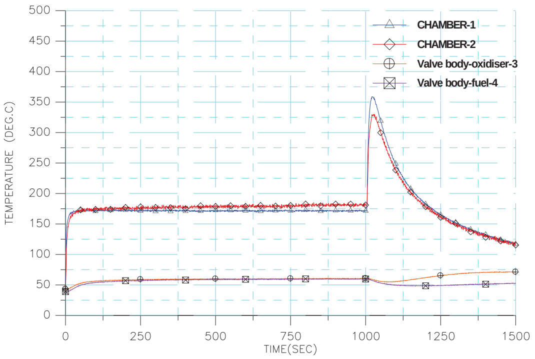

Fig-7 Temperature plot of 1000s firing

The pulse mode tests were carried out in various duty cycles ranging from 0.006% to 93%. Cold pulse tests were conducted at different electrical pulse widths (EPW) with an OFF duration of 120s. Fig -8 shows the variation of impulse bit at different EPW for cold pulses at normal supply pressures.

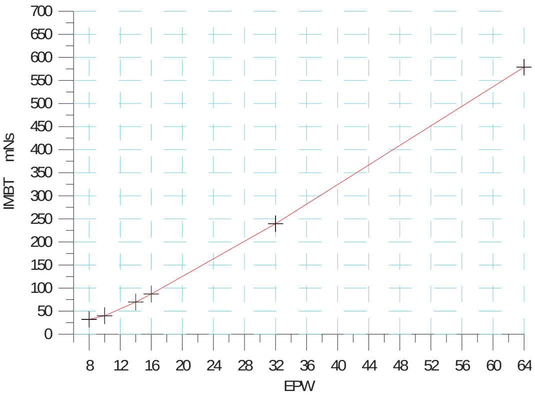

Fig-8

The impulse bit variation is linear from 10ms EPW onwards. Below 10 ms EPW it falls out of linearity due to the influence of dribble volume. Hot pulses were carried out for different duty cycles to demonstrate the capability of the thruster. The hardware temperatures are well within the acceptable limits in all the duty cycles.

A typical train of hot pulses with 16ms ON /50 ms OFF at nominal supply pressure is shown in Fig-9

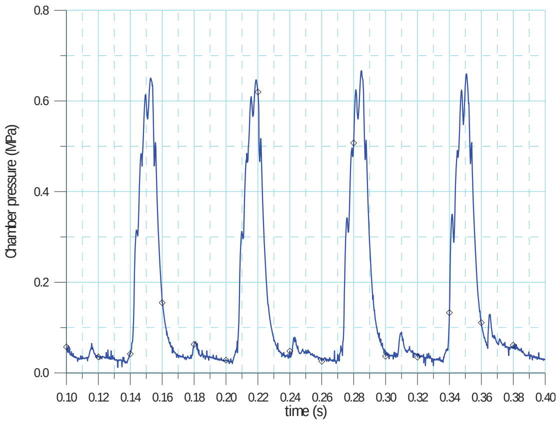

Fig-9

Flight Heritage.

After successful completion of development and qualification, 10 N thrusters were put into use from the year 2001 onwards. More than hundred flight thrusters were realized so far. Flight units were supplied for eleven geostationary spacecrafts till date. Eight thrusters were used in East and West locations in all spacecrafts.

The performance and hardware temperatures experienced on board are comparable to that of ground test values and the thrusters are working normally on board.

Conclusion.

LPSC/ISRO has successfully developed a high performance 10N thruster for its spacecraft application. Seven formal qualification thrusters were tested as per approved qualification matrix of ISRO. The capability of this thruster to perform in extreme condition on board is strongly demonstrated by qualification test data.

Performance mapping of thrusters were carried out over a wide range of parameters. At nominal operating condition of 1.65 MPa it delivers a specific impulse more than 290s. Pulse mode tests were carried out over a broad spectrum of duty cycles and temperatures were within the acceptable limits. More than 100 thrusters were produced and delivered for eleven spacecrafts. On board performance of all the thrusters are normal.

Acknowledgement

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Reference

1. G.Madhavan Nair, C.G.Balan et.al, “Earth Storable Bi propellant thrusters for Geostationary spacecrafts”, 3rd International Conference on Spacecraft Propulsion, Cannes, Oct-2000